INFLUENCE OF LIMING AND K FERTILIZATION ON THE NUTRITION OF SUGARCANE AND *DESMODIUM* SPECIES

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ABSTRACT

Growth and Ca, K, Al and Mn concentration of Desmodium species and sugarcane were studied in relation to the amounts of lime and K added to four Hawaii soils.

Sugarcane took up little (about 150 ppm) Al and usually relatively little Mn. As a result growth was usually independent of soil pH. Indications are that sugarcane can take up adequate amounts Ca from highly weathered soils at low levels of Ca saturation. Thus liming highly weathered soils to supply Ca for sugarcane need not be based on soil pH or percentage of the exchange complex saturated with Ca. Available Ca in the root zone is probably a more realistic criterion on which to base liming recommendations in this case. For soils which are very high in Mn (such as the Lahaina soil) liming to decrease Mn uptake in sugarcane may be desirable. In this case soil pH may be a suitable criterion for making lime recommendations.

Desmodium can accumulate large amounts of Mn. Plants growing on acid Lahaina soil contained Mn in excess of 12,000 ppm and only high rates of lime appreciably decreased Mn uptake from this soil. Indications were that Mn in excess of about 1000 ppm was highly toxic. Aluminum may also have been present in toxic concentrations in Desmodium plants. Soil pH control to eliminate toxicities of Al and Mn are suggested as essential management practices.

Desmodium accumulated large amounts of Ca (up to 3.5%) which demonstrates that tropical legumes are not necessarily poor in Ca. Furthermore, Desmodium was able to extract Ca even when the soils were at very low percentage Ca saturation.

An attempt to use free energy of exchange as a means for evaluating K:Ca balance was not successful. In some instances good growth was obtained within the range of values which had been suggested by Woodruff as being favorable. However, in some cases good growth was obtained at values in excess of those believed to be favorable.

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INTRODUCTION

Exchange cations adsorbed on the surface of soil colloids usually are assumed to be available to plants, although not all exchangeable cations are equally available for plant absorption. Important factors which affect the availability of exchangeable cations to plants are (1) the nature of colloids, (2) degree of cation saturation and (3) nature of complementary ions. Many explanations have been offered for differences in cation availability. Horner (1936) attributed differences to the relative energy of adsorption of different cations on clay surfaces. However no numerical value or relative order of energy of adsorption was given.

Jenny (1936) in his diagram of the qualitative relationship between complementary ions, used relative oscillation volume as a measure of adsorbability. The greater the oscillation volume, the less tightly the ion is held, and consequently the greater the availability of the ion to plants. Marshall (1944) has employed various methods for the measurement of cationic activity of exchange cation and used the term "cationic activity" almost synonymously with "ionic dissociation" or availability. No completely satisfactory explanation has yet been advanced for differences in the availability of exchange cations adsorbed on different clay minerals. According to Hendricks (1941) two types of forces attract cations to the surface of crystals: Coloumb type forces, due to electrostatic attraction and Van der Waal type forces. Van der Waal forces vary primarily with the nature of the ions absorbed, while Coloumb forces depend also upon the crystal structure of the mineral and the distance between the crystal

surface and the seat of isomorphous replacement within the crystal lattice.

There is little isomorphous substitution within the crystal lattice of kaolinite. Exchangeable cations are held on the surface of kaolinite mostly through the direct replacement of cations of hydrogen in $\overline{OH}$ groups of the lattice surface. Isomorphic substitution in montmorillonite provides sites having a range of energies for cation adsorption. The different forces of attraction thus created may account for some of the differences in the availability of exchange cations between soils containing montmorillonite and kaolinite. Recently, efforts have been made to investigate the ion exchange equilibria between cations and clay minerals. Exchange isotherms have been constructed which have illustrated the relative affinities of cations for exchange sites over wide ranges of cation concentration and composition.

Rate factors influence the delivery of cations from the exchange complex of the soil to roots of plants. Cation transport is associated with the concentration of anions in the soil solution. Undoubtedly, the rate of transfer of cations between the exchange complex and the plant root is adequate in soils containing normal complements of nitrates, sulfates, phosphates and bicarbonates. However, cation removal from exchange sites involves cationic exchange reactions. These reactions are governed by changes in free energy. Energy of exchange not only determines whether or not reaction will occur but also determine the balance among cations which will be exchanged from the soil.

Early investigators believed that the major benefit obtained by liming was due to neutralization of soil acidity. Later, the beneficial response from liming was shown to be due to many physical, chemical and biological factors. Although the function of calcium in plants is well documented, there are conflicting opinions in the literature as to whether calcium usually is one of the factors limiting growth on acid soils. One school of thought claims that benefits from lime applications largely are due to increased Ca ion concentration and another school claims that benefits are due to factors related to pH such as the solubility of Al and Mn. Marked influence of ions upon the absorption of other ions have been observed. For ions of the same valence, this influence is usually competitive in nature. On the other hand, the presence of ions such as Ca^{++}, Sr^{++}, Al^{+++} and Fe^{+++} has been observed to exert a stimulating effect on the absorption of K^{+}, Rb^{+} and Br^{-} under some conditions (Viets, 1944).

The object of the present investigation was to study ion exchange equilibria involving calcium and potassium; to study the nutritional balance of calcium and potassium as reflected by the free energy of reaction; to compare the manner in which different types of Hawaiian soil colloids release their calcium and potassium to growing desmodium and sugarcane plants; and to measure the effect of percentage calcium and potassium saturation of these soil colloids upon the magnitude of this release.

REVIEW OF LITERATURE

The discovery that colloids of many soils are predominantly crystalline clay minerals has set in motion many investigations on the chemical and physical properties of clays. Many of these investigations have been concerned with the influence of clays on the nutrition of plants.

Availability of exchangeable Ca from different types of colloids as affected by degree of Ca saturation

Mehlich and Colwell (1944) found that yield and Ca content of soybeans and cotton, grown on a montmorillonitic soil colloid increased with increasing Ca saturation, reaching a maximum at the highest level used: 80 percent Ca saturation. When equal amounts of Ca were supplied at each level of saturation both soybeans and cotton obtained more Ca from a kaolinitic than from a montmorillonitic systems. Great differences in Ca availability to soybeans were reported by Allaway (1945) from different types of clay colloids. The order of availability to soybeans of the exchangeable calcium from several colloids was peat > kaolinite > illite > and Wyoming bentomite > Mississippi bentomite. For every colloid the availability of exchangeable Ca was increased by increasing percentage Ca saturation.

Mehlich and Reed (1946) found that for a given level of Ca, the Ca content of the peanut shell was highest when the plants were grown in kaolinitic type colloid; but on the other hand, the highest content of Ca in the plant was found in plants growing on an organic colloid.

The first increment of Ca increased yield in the kaolinitic media. Yields levelled off above 40% Ca saturation. Below 60% Ca saturation (absolute amount of Ca held constant) yields of rye grown on kaolinitic colloid were higher than those grown on montmorillonitic colloid (Chu and Park, 1949). Beaton, et al. (1961) studied the influence of cation saturation on yield and cation composition of oats grown on two British Columbia soils high in organic matter. Increased cation saturation significantly increased: (a) oat yield on an Alouette soil (an organic soil) (b) calcium uptake from both soils (c) magnesium content of oats grown on the pit soil and (d) tissue potassium of oats grown on the Alouette soil. Clark and Hill (1964) suggested that the relationship between lime potential and percent cation saturation depends on the dominant exchange material in soils. A given value of lime potential, therefore, may not represent the same degree of cation saturation in all soils.

Soil pH, cation exchange capacity and ion exchange equilibria in soil colloid

Pratt (1961) found that the permanent charge of soils and sum of the basic metal cations plus Al were nearly equal. He reported that pH dependent CEC was very closely related to the amount of calcium carbonate required to neutralize soil acidity. The cation saturated, pH dependent charge sites of soil organic matter were reported to be the main factors contributing to the lime requirement of soils studied by Keeney and Corey (1961). Ross, et al. (1964) demonstrated that percentage cation saturation alone are inadequate criteria for evaluating lime requirement of nine Michigan soils. Yield response of

alfalfa to liming varied on different soil types at the same pH and could not be predicted from soil pH only. Turner, et al. (1965) concluded that 1/3 pAl - 1/2 pCa is directly related to the degree of Ca saturation of the clays but that the lime potential and pH are not. The lime potential was a function of the ion product $(Al)(OH)^3$ and the degree of Ca saturation, while pH is a function of these two variables and the activity of the Ca as well.

Nye, et al. (1961) obtained Ca:Al exchange isotherms for montmorillonite, kaolinite and White Store soil by leaching clay with solutions containing different concentrations of $CaCl_2$ and $AlCl_3$ and measuring the distribution of adsorbed cations. Isotherms for each material showed that Al was strongly preferred at total normalities of 0.02 and 1. The equivalent ion fraction of adsorbed Al in the clay was invariably greater than that in solution. The Ca:Al exchange coefficient (K'c) varied with total normality and Al saturation. Nye's method of saturation displacement was modified by Turner (1965) who displaced adsorbed ions by N $NaNO_3$ to obtain Ca:Al exchange isotherms on Wyoming bentonite. Isotherms again showed that Al was preferred. McLean, et al. (1966) determined Ni-Ba exchange selectivity coefficient for a montmorillonite clay by saturating 0.5 gm samples with 0.04 N concentration of $NiCl_2$ and $BaCl_2$. The values for the reaction

$$Ba_2 + N_i^{2+} \rightleftarrows Ni_2 + Ba^{2+}$$

ranged from 0.65 to 0.78 indicating a preferential adsorption of Barium. Isotopic exchange of K^{42}, Na^{24}, Rb^{86} and Ca^{45} was used to measure the equilibria between some arable soils and mixed chloride solutions of

the ion pairs K-Ca, K-Rb and K-Na. It was found that soils preferred K to Na in the K-Na systems and Rb to K in the K-Rb systems. These preferences were explained in terms of the standard free energy changes for the exchange reactions (Deist and Talibudeen, 1967). The non-specific (Gapon) and specific exchange sites were located by Beckett and Nafady (1967) in K:Ca exchange equilibria of soils. It was reported that the specific sites take up K more slowly from solution than the non-specific sites. The specific sites were attributed to the wedge-shaped interlayer openings between clay plates by weathering from which exchange is diffusion controlled.

Woodruff (1955) investigated broad limits, or ranges, for energies of exchange in relation to the nutritional balance of potassium and calcium in soils. Energy of exchange is a measure of the intensity factor in the delivery of a balanced supply of nutrient cations from the exchange complex of the soil to the growing plant. Energies of exchange for the replacement of calcium by potassium in a soil may be computed from the cationic composition of water extracts from the soil. For practical purposes the activities of metallic cations in a very dilute electrolyte are equal to their concentrations. The energy of exchange, ΔF in calories per chemical equivalent at 25°C may be computed from the relation:

$$\Delta F = 1364 \log \frac{aK}{\sqrt{a_{Ca}}}$$

where a_K and a_{Ca} express the activities in moles per liter of potassium and calcium, respectively, in the dilute electrolyte. Woodruff obtained energy of exchange values from the above equation and pointed

out that K availability may be related to the change in free energy of exchange for two cations computed from the cationic composition of dilute electrolyte or water extracts from the soil. He concluded that energy of exchange between -2000 and -3500 calories represent suitable balances between K and Ca. Values > -3500 calories were associated with K deficiency in plants and values < -2000 were associated with excess amount of K in relation to the amounts of Ca present.

Ca and K interaction in soils and plants

Ca and K interactions are important in plant nutrition. Lime or potassium applied alone to soils may often be of little value; in some instances, applications of either lime or potassium have had a deleterious effect on crop yields, whereas the two materials have been beneficial when applied together. Such observations demonstrate the importance of a proper balance between calcium and potassium in soils.

Ca and K interaction in soils

Seatz and Winters (1943) have reported that K release and fixation depend on the amount of K added to the soils. At the lowest rate of addition more K was recovered by leaching than had been added. At the highest rate of application only about 70% of the added K was recovered.

Marshall and Barber (1949) and Mclean (1949) found substitution of Ca for H to increase K activity in systems containing kaolinite, illite, halloysite and montmorillonite. Wadleigh (1949) has reviewed numerous papers which show that high levels of exchangeable K decrease Ca availability. No type-of-colloid effect, however, was apparent.

Marshall (1950) reported that increasing amounts of exchangeable K reduces Ca activity markedly in the case of montmorillonite, whereas in the case of kaolinite Ca activity is actually increased when K is substituted for exchangeable H.

Considerable K was fixed in Mardin Silt loam as a result of liming. Potassium in the soil solution was found to decrease as lime addition increased up to 78% cation saturation. In the presence of excess lime, however, K in the soil solution was increased (York, et al., 1954). Wiklander (1950) showed that liming, which replaces firmly bound Al and H with less tightly held Ca, promotes the adsorption of cations such as K, thus decreasing the concentration of cation other than Ca in the soil solution. Mahilum, et al. (1970) found that limed Akaka soil retained more K and Na than did unlimed soil. They suggested that this effect may have been the result of depressed leaching of monovalent ions when Ca replaced Al as the complementary ion on the exchange complex and pH dependent negative charge was increased by increased soil pH.

Interaction of Ca and K in plants

Hunter, et al. (1943) found that as long as the soil contained an adequate amount of potassium, satisfactory yields of alfalfa could be produced with high Ca-K ratios. They suggested that for economic reasons the Ca-K ratios should be maintained relatively high in order to decrease heavy absorption of potassium. Viets (1944) showed that a variety of polyvalent cations accelerate K and Br absorption, Ca being the most effective. Calcium, Mg, Sr, Ba and Al ions decreased the absorption of K and Br, but no regular series of efficiencies could be

determined. This was known as the "Viets Effect." The nature of the calcium effect was explained by Kahn and Hanson (1957) by using kinetic manipulations. They concluded that calcium affects two absorption reactions, one of which is stimulated while the second one is inhibited. Helder (1958) and Laties (1959) proposed that Ca is essential for maintaining the permeability of root membranes. Jacobson, et al. (1960) concluded that calcium could increase, decrease or have no effect on the uptake of various monovalent ions, dependent on the pH of the solution. The same investigators demonstrated that the presence of Ca could completely change the interrelationships between absorption of different monovalent cations such as K and Li.

Calcium is essential for the integrity of absorption mechanisms (Epstein, 1961). He showed that absorption of K or Rb is much less affected by interfering ions in the presence of calcium than in its absence. Waisel (1962) suggested that the "Viets Effect" results from changes induced by Ca in the permeability of membranes. Calcium causes an increase in the rate of diffusion of K or Rb through the membrane, but a decrease in the rates for Na, Li, and probably H. He also demonstrated that divalent ions affect the selective permeability or the cell's outer protoplasm barriers -- probably plasmalemma. Increasing soil pH from 5 to 8 increased Ca and decreased K, Mg and Mn in lucerne (Dionne and Rolapleszczynski, 1964).

Macleod and Bradfield (1963) reported that while lime may be sufficient to establish alfalfa seedlings, an adequate supply of K is essential for survival and maintenance of the established stand. Loneragan and Snowball (1968) examined calcium concentrations in the

tops and roots of 30 grasses, cereals, legumes and herbs over a wide range of calcium concentrations from 0.3 to 2.5 μM. Yield increased greatly, while calcium concentrations in the top remained constant. By contrast, increasing solution concentrations from 10 to 1000 μM markedly increased concentrations in tops but in most species had relatively small effects on yield.

Liming and micro-nutrient relationship in plant nutrition

Ouellette and Dessureaux (1958) found that Al tolerant alfalfa clones contained lower concentrations of Al and Ca in their roots than did an Al sensitive clone. Calcium was believed to act in two ways to reduce the toxicity of Al. First, by reducing the uptake of Al; and second, by immobilizing part of the absorbed Al in the roots; thus preventing its translocation to plant tops. Wheat varieties differed in their tolerance to acid soil in Ireland and in some varieties yield responses to lime were significantly correlated (negatively) with Al concentrations in plant tops (Neenan, 1960). Increased aluminum concentration was associated with decreased calcium concentration in sunflower roots (Hortenstine and Fiskell, 1961).

Rees and Sidrak (1961) stated that Al toxicity may be associated with its effect on the K/Ca ratio of plants while manganese affects both the Fe/Mn and K/Ca ratios. Increase in concentration of either iron or manganese in relation to the other depressed accumulation of other metals in both leaves and the whole plant of dwarf kidney bean. An increase in calcium concentration decreased absorption of both metals. Calcium level was found to be the determining factor for the

optimum Fe/Mn ratio for healthy plants. Walter and Hardy (1964) emphasized that soybeans grown under strongly acid conditions in Arkansas exhibited abnormal growth characteristics. Nutrient uptake studies showed that Mn toxicity symptoms were dominant in the syndrome reflecting the acid soil condition.

The Al sensitive "Monon" wheat variety induced a lower pH around its roots, in both nutrient solution and soil than did the more tolerant "Atlas 66" variety. Greater Al sensitivity in the "Monon" variety was attributed, at least in part, to greater Al solubility in its root zone (Foy, et al., 1965). Clarkson (1965) concluded that Al inhibits cell division in onion while Rorison (1965) and Clarkson (1966) reported that Al reduced oxidative phosphorylation in sanfoin and barley. No direct relationship between pH and soluble Al was demonstrated by Macleod and Jackson (1967), although the highest soluble Al concentration occurred at lowest soil pH levels. Analyses of 30 representative samples of surface soil taken from farmers' fields showed that soluble Al concentration at pH 4.0 ranged from 3.5 to 4.8 ppm while at a pH of 5.0 it ranged from 0.2 to 2.8 ppm.

MATERIAL AND METHODS

Description and preparation of experimental soils

The soil used for laboratory experiments represent four great soil groups of Hawaii. They came from three different islands of the Hawaiian chain and developed under a wide range of environmental and climatic conditions. These soils groups have been described by Cline, et al. (1955). The four soils and some of their important characteristics are as follows:

1. Akaka soil. This soil is a Typic Hydrandept. Soils of this sub group are derived from volcanic ash and have developed under heavy rainfall (120-300"). The soil occurs at elevations of 800-6,000 feet and is continually wet in its natural condition. It holds about 200 percent water. On drying it becomes irreversibly dehydrated. The soil material consists of clay sized minerals which are amorphous to X-ray diffraction and is rich in hydrated Fe and Al oxides. The organic matter content, on an oven dry basis, is about 15% to 20%. The inorganic fraction of the soil is weathered. The soil is highly leached, and exchangeable basic cations have been reduced to very low levels. Soil pH is about 5.0. The soil was collected from an idle field on the Pepeekeo Sugar Plantation above Akaka Falls. Kanehiro and Chang (1956) found the CEC (determined with neutral IN ammonium acetate) of an Akaka surface soil to be 82 meq/100 gm. Analysis of cations extracted by Kanehiro and Chang indicated a base saturation of only 2%.

2. Kapaa soil. This soil is a Typic Gibbsihumox. It is highly weathered. Oxides are the dominant minerals. As a Latosol it approaches the end product of soil formation (Sherman, 1958). The soil occurs on lower mountain slopes between elevations of about 200 and 1,000 feet. Soils of this group give a good gibbsite peak by X-ray analysis. The soil is almost devoid of cations and silica. Soil pH is about 4.9. The soil was collected from the Bauxite project plots near the Kauai Branch Station of the University of Hawaii.

3. Lahaina soil. This soil is a Typic Torrox. This soil has developed on basaltic material in a semi-arid to sub-humid climate of tropical regions having a pronounced dry period (Sherman and Alexander, 1958). The clays belong mostly to the kaolin group with considerable amounts of Fe oxides (x-ray analysis). The soil contains manganese oxide concretions. Soil pH is about 5.0. The soil was sampled from an unused corner of a Dole Company pineapple field on the Meialani cemetery road, Oahu.

4. Pearl Harbor clay. This soil is a Typic Tropoquept derived from alluvial parent material. X-ray analysis showed that the dominant minerals are of the kaolin type. The pH of the soil is about 4.5. The soil was sampled from a banana planting near the mouth of Waihole stream on windward Oahu.

All soils except Akaka were air dried and screened through a 16 mesh sieve for laboratory work. The soil was stored in double polyethylene bags. Care was taken to avoid drying the Akaka soil. Samples were drawn to determine moisture content.

Ca-K exchange equilibria in soils

Selectivity curves by saturation displacement: One gram of air dry soil was leached in a small tube with chloride solution ($CaCl_2$ + KCl) of 0.01 N (total normality) containing different proportions of the cations, until the effluent and influent concentrations were the same. After equilibrium was attained, the occluded solution was displaced by methyl alcohol until no Cl was detected. The exchangeable ions were displaced by leaching with 1 N ammonium acetate. Determinations were done in duplicate.

The exchange equilibrium was established by leaching soil samples with the following solutions:

Total normality	Ca-normality	K-normality
.01	0.000	0.010
.01	0.002	0.008
.01	0.004	0.006
.01	0.006	0.004
.01	0.008	0.002
.01	0.010	0.000

Determination of calcium and potassium in equilibrium solution: Calcium was determined by EDTA titration as described by Chapman and Pratt (1961). Potassium was determined by flame photometry.

Apparent exchange coefficient

Apparent exchange coefficients were calculated for various values of $\frac{C}{Co}$ corresponding to the selective curves as presented in Figure 1

(Amphlett and Macdonald, 1956, and Nye, et al., 1961). The following formula was used:

$$K'c = \frac{(\frac{Q}{Qo})^{Z_A}\ (1 - \frac{C}{Co})}{(\frac{C}{Co})^{Z_A}\ (1 - \frac{Q}{Qo})} \cdot \frac{1}{C_o^{Z_A-1}}$$

$K'c$ = Apparent exchange coefficient

C_o = Total electrolyte concentration of the equilibrium solution in equivalent liter

C = Equilibrium concentration in the solution

$\frac{C}{Co}$ = The equivalent ion fraction in solution

$\frac{Q}{Qo}$ = The equivalent ion fraction of adsorbed ion

Z_A = Valency of ion A

Energies of exchange for soils

The method followed for energies of exchange for four soils was as described by Woodruff (1955). The original soil samples and samples of the same soils following sugarcane and Desmodium growth were saturated with distilled water in Buchner funnels. After one hour the funnels were placed on suction and the solution extract were collected for 15 minutes. These were analyzed for potassium and calcium. The energy of exchange was computed from the equation (Woodruff, 1955):

$$\Delta F = 1364 \log \frac{a_k}{\sqrt{a_{ca}}}$$

ΔF = The energy of exchange in calories per chemical equivalent at 25°C

a_k = K activity in moles/liter

a_{ca} = Ca activity in moles/liter

Determination of lime requirement

Cation exchange capacities of soils were based on titration curves to pH 7.0 using $Ca(OH)_2$ since curves prepared using $CaCO_3$ did not reach pH 7 for these soils. The procedure was as follows:

Twenty-five gram soil samples (O.D. basis) were weighed into 100 ml beakers. Distilled water was added to form a slurry and various amounts of $Ca(OH)_2$ were added. Slurry pH was determined on the first, 7th and 14th days. Readings were essentially constant on the 14th day. Amounts of $Ca(OH)_2$ required to raise soil pH to 7.0 were estimated from the titration curves. This was considered to be the cation exchange capacity of the soils and, for the purposes of this study, was considered 100% Ca saturation. All calculations of percentage Ca and K saturations were based on these values. The following are lime requirements from the titration curves (O.D. basis).

Soil	Lime requirement (CEC) (meq/100 gm at pH 7.0)
Akaka	37.00
Kapaa	24.00
Lahaina	15.00
Alluvial	53.70

Green house procedure

Leaching of soils: The Pearl Harbor and Lahaina soils initially contained more Ca and K than the minimum experimental levels desired.

Therefore, it was necessary to leach excess cations from these soils before the experimental levels of Ca and K were established. This was achieved by leaching the soil samples with 0.05 N HCl. Excess HCl was removed by washing soils with distilled water until free of chloride. No leaching was found necessary in the case of the Akaka and the Kapaa soils because these soils were highly leached and the natural content of exchange cations was low. The pH values for the four soils prior to liming were 5.0 (Akaka), 4.9 (Kapaa), 4.0 (Lahaina) and 3.0 (Pearl Harbor).

Potting procedure: Perlite was added to Akaka, Kapaa and Alluvial soils so that cation exchange capacity per unit volume of soil was constant. Two plant species, sugarcane and Desmodium intortum, were used for the green house study. Desmodium was grown in one gallon can lined with polyethylene bags. Sugarcane was grown in 5 gallon cans lined with polyethylene bags. A randomized complete block design with two replications was used for each species constituting a separate experiment. About 300 cuttings of Desmodium intortum were grown in vermiculite for 3 weeks in the mist chamber of the Horticulture Department. One-eye seed pieces of sugarcane (Variety 57-7209) were obtained from the Kunia research field station, HSPA. About 300 cane sets were planted in small trays of quartz sand. They were allowed to grow for about 3 weeks before being transferred to the potted soil.

Treatments were factorial combinations of the following Ca and K levels.

Ca saturation (%)	100, 80, 40, 20 and 5
K saturation (%)	1 and 5

In the case of the Akaka and the Kapaa soils 100% Ca saturation was not included. This was done because similar type of work in the literature had indicated that soils with high organic matter and high amorphous material release Ca at lower degree of Ca saturation compared to soils belonging to 1:1 and 2:1 groups. A blanket application of 200 ppm N as urea, 500 ppm P as H_3PO_4, 100 ppm Mg as $MgSO_4$, 50 ppm Zn as $ZnSO_4$, 1 ppm Mo as ammonium molybdate and 2 ppm B as H_3BO_3 were given to each soil, followed by addition of Ca as $Ca(OH)_2$ and K as KCl according to the different treatments. Then each soil was thoroughly mixed several times and was allowed to equilibrate with the added chemicals for a week. Seven days after addition, two selected seedlings of Desmodium or sugarcane were transplanted to each pot.

Plant sampling: Desmodium plants were harvested and divided into leaves, stems and roots 4 weeks after transplanting. Leaves and stems together, excluding roots, were called as Desmodium tops. Desmodium tops were oven dried at 70°C. Sugarcane was harvested at 6 weeks and the ratoon was allowed to grow for 2 months and harvested thereafter. Plants of the first harvest were divided into leaves and sheaths. Leaf sheaths 3, 4, 5 and 6 were sampled from each plant as an indicator tissue. The second sugarcane harvest was divided into leaves, sheaths 3, 4, 5 and 6 and roots. Leaves represented above ground portion of the plant excluding 3, 4, 5 and 6 sheaths and roots. All the parts were washed with distilled water and then oven dried at 70°C.

Roots of Desmodium and sugarcane were washed from the soil with distilled water, placed in a nylon net, washed in a dilute Dreft detergent solution (0.01%), and rinsed three times in distilled water.

Roots were washed again by suspending the nylon net above the blades of a Waring Blender (with 400 ml distilled water) for 30 seconds, dipping for a total period of 30 seconds in 3 successive beakers containing 900 ml of 0.01 N HCl, followed by rinsing for 30 seconds in distilled water. Entrained solution on roots was removed by hand slinging. Roots were then oven dried at 70°C.

Analytical methods employed for analyses of plants and soils

Plant analysis: Ground material was digested overnight in micro-Kjeldahl flasks with 15 ml of 2:1 nitric perchloric acid followed by heating until 1-2 ml of liquid was left and dense white fumes were visible. Digested samples were diluted with water, transferred into volumetric flasks and brought to volume with distilled water. Blank samples were also processed in the same way.

Calcium, potassium and aluminum: Ca, K and Al were determined with a Perkin-Elmer atomic absorption spectrophotometer (Model 303). Potassium was determined with a Beckman DU flame spectrophotometer.

Soil analysis: Samples of the soil materials in different experiments were analyzed for pH, Ca and K. The following analytical procedures were followed for soil samples.

Soil pH. Soil pH was determined with a Beckman pH meter on a soil:water slurry equilibrated for 30 minutes.

Calcium. Calcium was determined by the EDTA titration method as described by Chapman and Pratt (1961).

Potassium. Potassium was determined with the Beckman DU flame spectrophotometer.

Note: All the data on the plant growth and chemical composition of plants and soils were expressed on an oven dry basis. Values presented in graphs and tables relating to yields, chemical compositions of plant parts and free energies of exchange are means of two replications.

RESULTS AND DISCUSSION

It is well known that the "activity" and chemical release of Ca from soils and the uptake of Ca by plants is influenced by the type of soil colloid. Most of the studies have emphasized members of the 1:1 and 2:1 lattice clays of the temperate zone. Very little consideration has been given in tropical areas to the influence of soils belonging to the 1:1, 2:1 and hydrated Fe and Al oxide groups on the release of Ca and K. In the present investigation, relationships among cations (Ca, Al and K) and soils (those containing primarily oxides and those containing primarily 1:1 group clay minerals) has been studied. The influence of cation-colloid interaction has been related to Ca and K nutrition and growth of sugarcane and Desmodium plants.

Calcium-Potassium Exchange Equilibria in Hawaiian Soils

Isotherms showing exchange equilibria between soils and solutions containing K and Ca show that (i) K was preferred to Ca in the poorly crystallized Akaka soil; (ii) Ca was slightly preferred to K in the Kapaa soil; (iii) neither Ca nor K was preferred by the Lahaina soil; and (iv) Ca was preferred to K in the Pearl Harbor soil (Fig. 1 and Table I).

Differences were observed in the adsorption of Ca and K by the four experimental soils. The ratio K:Ca adsorbed was greater in the Akaka soil than the ratio K:Ca in other soils. The Pearl Harbor soil was the lowest in K:Ca ratios. Wiklander (1950) attributed K "fixation" upon liming as partly due to less H and Al saturation at higher pH values and partly due to replacement of adsorbed Ca by K. Liming four

FIGURE 1. SELECTIVITY CURVES FOR ACID SOILS EQUILIBRATED WITH CaCl$_2$ + KCl IN DIFFERENT RATIOS (TOTAL CONCENTRATION, 0.01N) BASED ON VALUES IN TABLE I.

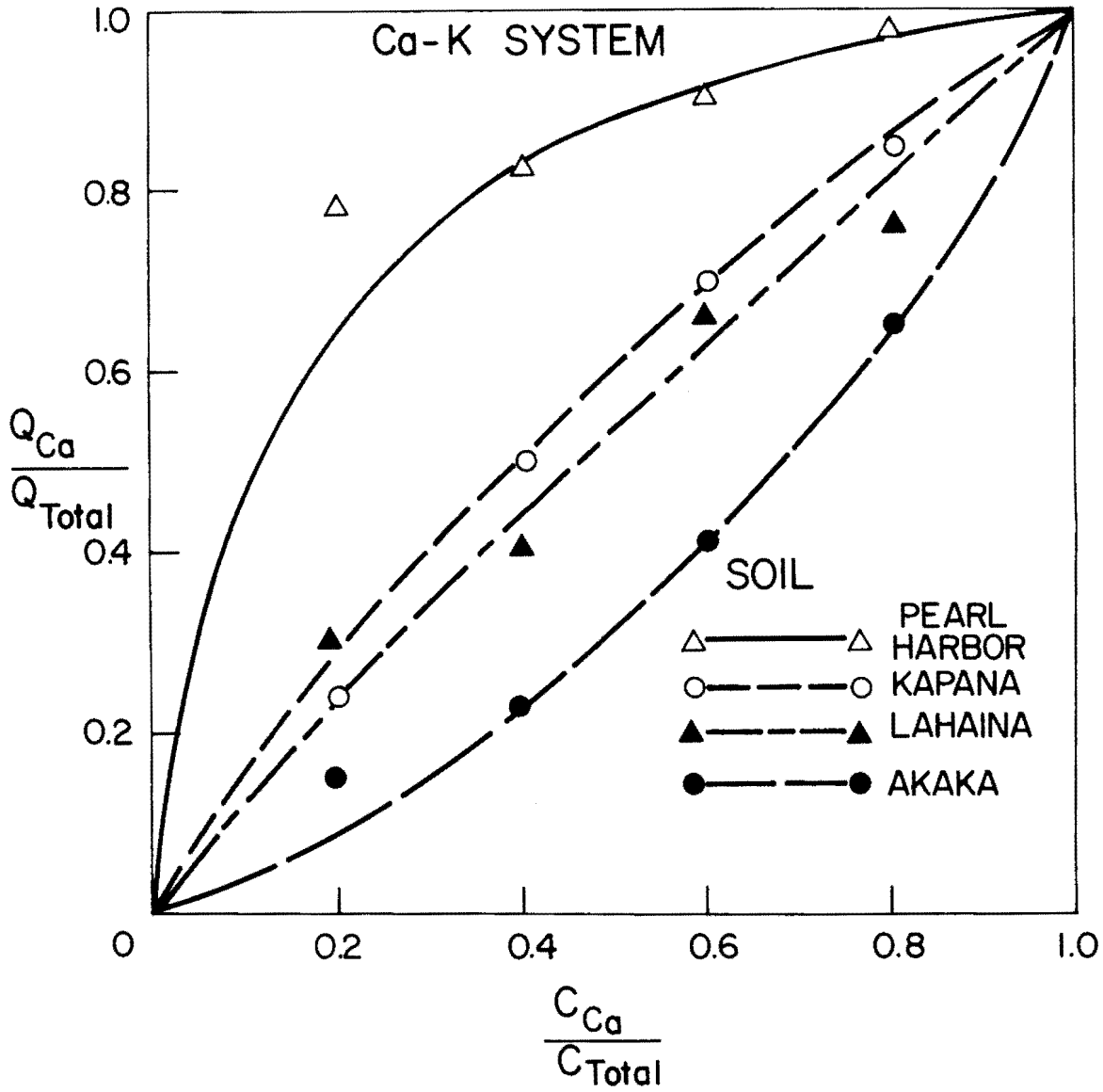

Ca-K SYSTEM
1.0
0.8
0.6
0.4
0.2
0
0.2
0.4
0.6
0.8
1.0
$\frac{Q_{Ca}}{Q_{Total}}$
$\frac{C_{Ca}}{C_{Total}}$
SOIL
PEARL HARBOR
KAPANA
LAHAINA
AKAKA

TABLE I. EQUILIBRIUM DATA FOR CA-K EXCHANGE AT 25°C FOR FOUR HAWAII SOILS (C_{TOTAL} = 0.01N)

Soil	C_{ca}	$\frac{C_{ca}}{C_{Total}}$	Q_{Total} [CEC,meq/gm]	Q_{ca} [meq/gm]	Q_k [meq/gm]	$\frac{Q_{ca}}{Q_{Total}}$
	0.000	0.00	0.048	0.000	0.048	0.00
	0.002	0.20	0.041	0.006	0.035	0.15
Akaka	0.004	0.40	0.030	0.007	0.023	0.23
	0.006	0.60	0.034	0.014	0.020	0.41
	0.008	0.80	0.032	0.020	0.010	0.65
	0.010	1.00	0.050	0.050	0.000	1.00
	0.000	0.00	0.024	0.000	0.024	0.00
	0.002	0.20	0.020	0.005	0.015	0.24
Kapaa	0.004	0.40	0.019	0.009	0.010	0.50
	0.006	0.60	0.025	0.017	0.008	0.70
	0.008	0.80	0.027	0.023	0.004	0.85
	0.010	1.00	0.036	0.036	0.000	1.00
	0.000	0.00	0.067	0.000	0.067	0.00
	0.002	0.20	0.074	0.020	0.054	0.30
Lahaina	0.004	0.40	0.068	0.026	0.042	0.40
	0.006	0.60	0.080	0.055	0.025	0.68
	0.008	0.80	0.076	0.058	0.018	0.76
	0.010	1.00	0.064	0.064	0.000	1.00
	0.000	0.00	0.012	0.000	0.012	0.00
	0.002	0.20	0.037	0.024	0.008	0.78
Pearl	0.004	0.40	0.034	0.028	0.006	0.82
Harbor	0.006	0.60	0.054	0.049	0.0052	0.90
	0.008	0.80	0.066	0.065	0.001	0.98
	0.010	1.00	0.064	0.064	0.000	1.00

Canadian soils to raise pH to about neutral increased K adsorption slightly; usually the amount of K in solution was lower in the limed than in the corresponding unlimed samples (Maclean, 1962). The amorphous inorganic colloids of a number of unconsolidated marine sediments contained a relatively large amount of K despite the unfavorable Na/K ratio of the sea water (Van Reeuwijk and De Villiers, 1968).

It is well known that volcanic ash soils of Hawaii contain considerable amounts of hydrated Fe and Al oxides. Twenty to forty percent free oxides are not uncommon in these soils. The presence of iron oxides seed to be associated with positive charge (Clark, 1960). Fieldes (1962) reported that allophanes develop increasing negative charge as pH increases above pH 5 whereas illitic and montmorillonitic clays retain most of their negative charge below pH 5. Anion retention and positive charge on allophane increases with decreasing pH. As mentioned previously, the Akaka soil did not show preference for Ca as shown in Fig. 1. Mehlich (1952) reported that cation-anion-exchange capacity ratios of colloids of the 1:1 and 2:1 lattice families range between 1 and 3. They are less than 1 when appreciable amounts of goethite, gibbsite and hematite are present. The presence of these minerals in the Akaka soil has been reported by Tamura, Jackson and Sherman (1953). It was also emphasized that the hydrated oxides may affect the position and nature of Ca bond on the cation exchange surface. Oxides seem to bind Ca loosely which affords a high release of Ca from soils which are predominantly hydrated soils.

Several mechanisms may be involved in the inability of Ca to compete with K for exchange sites on an equal basis in the Akaka soil. (1) Although the soil was leached with Ca and/or K solutions, some of the exchangeable Al was undoubtedly retained. Mehlich (1952) has shown that Ca release was greater from Ca-Al-H clay system than that from a Ca-H clay system. (2) Surface area is very extensive in the Akaka soil and net negative charge is low. Elgabaly and Wiklander (1949) have used roots to demonstrate that compared with roots with high acidoid content (high CEC) roots with low acidoid content (low CEC) tend to adsorb K relatively strongly as compared with Ca. (3) The presence of positively charged sites would tend to repel cations especially polyvalent cations. The presence of a component of positive charge has been demonstrated for amorphous soils (Fieldes, 1962) and for the Akaka soil in particular by Mekaru (1969). (4) Coulter (1969) reported that K adsorption by soils may be attributed to K being strongly bound on specific sites or else K is adsorbed on sites which are sterically hindered from adsorbing cations of high valency.

Valence, hydration of the ion, and nature of clay minerals are dominant factors in determining energies of adsorption and release. Divalent ions are adsorbed more strongly than monovalent ions. Weakly hydrated ions are held more tightly than those surrounded by large water hulls. Barshad (1948) and Hutcheon (1966) have emphasized the effect of hydration in relation to cation adsorption by soil-colloids. The K ion is easily dehydrated compared to other ions. It has been reported that K ions may not be hydrated (Hendricks, et al., 1940). Deist and Talibudeen (1967) attribute preferential adsorption of K by

soil colloids to hydration of the Ca ion. Hutcheon (1966) reported that the Ca ion are hydrated to a greater extent on the clay and the energy of hydration per water molecule is much greater than for the K ion. Hydration will reduce the attraction between the ion and the clay in the same way as other forces between ions in a crystal are diminished by hydration of the ions when the crystal dissolves. Van Reeuwijk and De Villiers (1968) indicate that synthetic aluminosilica gels fix K in varying amounts against replacement by common alkali and alkaline earth cations; the larger the solvated size of the replacing cation, the greater was the amount of K retained. Thus, hydration of the Ca ion may be one of the factors contributing to preferential adsorption of K in the Akaka soil.

It is already known that the inorganic colloids of the highly weathered Akaka soil have low permanent charge in relation to the extensiveness of their surfaces. Much of the charge is pH dependent and at the pH commonly encountered positive charge may exceed negative charge (Mahilum, Fox and Silva, 1970). On the basis of Fe and Al oxides present and the published observations on cation and anion adsorption, the permanent and pH-dependent charges of Akaka, Kapaa, Lahaina and Pearl Harbor soils might be as follows:

Permanent charge	Akaka < Kapaa < Lahaina < Pearl Harbor
pH dependent charge	Akaka > Kapaa > Lahaina > Pearl Harbor

Van Reeuwijk and De Villiers (1968) reported that the K fixing capacity of the alumina silica gels was pH dependent. The fixation of K increases as the pH at which K saturation took place was raised from pH 4 to 10. Somewhat contradictory results were reported by Ayres

(1953), Page and Ganje (1964). Ayres reported that the ability of Hydrol Humic Latosol to retain K from KCl was very slight; from K_2SO_4 it was considerable, and from various K phosphates, marked. Adsorption isotherms of Hawaiian soils clearly showed that phosphate adsorption capacity of Akaka soil was substantially greater than soils belonging to the 1:1 group (Fox, et al., 1968). Mekaru (1969) further demonstrated that phosphate may be adsorbed with consequent increase of CEC or increased soil pH. Evidence in support of pH dependent K adsorption have been presented by Schuffelen and Van Der Marvel (1955), De Villiers (1967) and Bartlette and McIntosh (1969). Results obtained for wet fixation by hydrogels showed that ability to replace K decreased in order of increasing ionic potential (charge radius = 0.7 for NH_4, 0.75 for K, 1.0 for Na, 2.0 for Ca and 3.0 for Mg) and thus hydrated ionic size (Van Reevwijk and De Villiers, 1968).

Jarusov (1937) explained that in a mixed system, the activity of the cation having the greater bonding energy would be lower than in the corresponding homionic system and the cation which is more loosely held would show an unusually high activity. In the present experiment, Ca-K systems of Kapaa and Pearl Harbor soils indicate higher K activity than Ca. This suggests that K is loosely held by these soils.

McLean and Marshall (1948) measured the activity of Ca and K in H-K, H-Ca and K-Ca systems prepared with different proportions of cations. It is now generally believed that the H-clays of these investigations were really Al-clays or at best Al-H-clays. In the case of Wyoming bentonite (2:1) they found that Ca increased the K activity over the K-H system. The effect was small for small amounts

of Ca but became large when the system contained small amounts of K. Thus, it appeared that the Ca ion is more powerful than the H(Al) ion in preempting positions of high bonding energy in the case of Wyoming bentonite. Marshall (1948) noted that below 70% Ca saturation, the montmorillonite (2:1) clays are characterized by an extremely low fraction of active Ca and hence by a high energy of adsorption for the Ca ions. In the case of kaolinite there is no region where Ca was so tightly held. Ionization of Ca was much greater for kaolinite than for the montmorillonite clays.

Relative Ca and K adsorption by the experimental soils was not precisely related to the amount of $Ca(OH)_2$ required to raise soil pH to 7.0 (for the purpose of this discussion considered to be the cation exchange capacity). The exchange capacities of the four soils were in the following order:

Pearl Harbor > Akaka > Kapaa > Lahaina

Mattson and Larsson (1945) and Elgabaly and Wiklander (1949) noted that with materials having different exchange capacities and containing adsorbed monovalent and divalent ions, the one with the higher exchange capacity will release its monovalent ions relatively more readily and its divalent ions less readily to the outside solution than the one with lower capacity. On the basis of the above finding, greater Ca adsorption by the Akaka soil compared to Kapaa and Lahaina soils would be expected because of relatively high cation exchange capacity of the Akaka soil. However, the permanent charge on the Akaka soil is very low. Mahilum, et al. (1970) estimates the charge to be 4 meq per 100 grams of moist soil (about 45% dry matter). Besides this, the Akaka

soil has high specific surface so that charge density is extremely low. The complementary ion principle (Jenny and Ayres, 1939) states that the release of a given ion is proportionately greater, the smaller the oscillation volume of the complementary ion. From what has been said about the Akaka soil, very large oxcillation volumes might be expected and relative to K the oscillation volume for Ca should be much greater in the Akaka soil than for the Kapaa and Pearl Harbor soils.

Apparent Exchange Coefficient

Exchange coefficient values were calculated according to the equation given in the materials and methods chapter. Some calculated values for the apparent exchange coefficient (K'c), for Ca-K exchange with Akaka, Kapaa, Lahaina and Pearl Harbor soils are shown in Appendix Table I. The mean apparent exchange coefficients were in the following order:

Pearl Harbor > Kapaa > Lahaina > Akaka

These values were much higher for the Pearl Harbor soil than for the other soils. In the case of the Akaka soil which preferred K ions, values were the lowest. In general, values became smaller as $\frac{C_{ca}}{C_o}$ increased and were larger at low Ca saturation except that values increased until $\frac{C}{C_o} = 0.6$ and then declined in the Kapaa soil.

Soil pH and Ca Saturation Relationships

Changes in soil pH with addition of lime and KCl were very different for the experimental soils (Table II). The highly weathered

TABLE II. SOIL PH IN RELATION TO PERCENT CA AND K SATURATION OF HAWAIIAN SOILS[a]

Cation Saturation (%)		Soil pH			
Ca	K	Akaka	Kapaa	Lahaina	Pearl Harbor
5	1	5.55	5.00	4.50	3.80
20	1	6.00	5.70	4.80	4.20
40	1	6.30	6.40	5.30	4.70
80	1	6.95	7.10	6.55	6.65
100	1	-	-	7.0	7.20
5	5	5.45	4.90	4.35	3.50
20	5	5.90	5.60	4.70	4.00
40	5	6.30	6.20	5.30	4.50
80	5	6.85	7.00	6.50	6.50
100	5	-	-	6.70	7.10

[a]Soils as limed and fertilized for pot studies. Saturation values of 100% correspond to amount of Ca as $Ca(OH)_2$ required to titrate the soil to pH 7.0.

soils gave higher pH values than the less weathered soils at each level of Ca saturation; and, of the less weathered soils, pH of the Pearl Harbor soil was generally lower. For example, pH values for 20% Ca and 1% K saturation were as follows:

Soil	pH
Akaka	6.0
Kapaa	5.7
Lahaina	4.8
Pearl Harbor	4.2

Mehlich (1941) found the pH at 25% Ca saturation to be 5.3 for kaolinite, 3.8 for montmorillonite, 3.4 for illite, and 4.8 for a muck soil. Kanehiro and Chang (1956) reported that a soil of the Humic Ferruginous Latosols group may have pH of 4.1 with cation saturation below 10%, while another soil of the Hydrol Humic Latosol group may have a pH of 6.0 at the same cation saturation. Marshall (1944) reported the order of H ionization from clay minerals as kaolinite < illite < montmorillonite.

Influence of Ca and K Saturation of Soils on Plant Yield and Chemical Composition

Sugar cane yield

Cane yields of the first harvest were highly significant in response to percentage Ca saturations and soils. Yields also responded significantly to the soil and K interaction (Appendix Table XVII). Yields were best at the lowest Ca and K level of Akaka and Kapaa soils (Table III and Figure 2). Results from the Pearl Harbor and Lahaina soils suggest a small increase from Ca up to 20 or 40% saturation followed by decline at 80 or 100% Ca saturation. Yields increased with increasing Ca saturation of the Akaka soil.

On the other hand, yields of the second harvest responded significantly to the four soils (Appendix Table XVII). Yields were also significantly affected by the soil and Ca interaction. There was an increase with increasing Ca saturation of the Akaka soil. On the contrary, yields were best at the lowest Ca saturation of the Kapaa soil. Yields substantially increased at 80 and 100% saturation of the Lahaina soil. The highly weathered Akaka and Kapaa soils gave substantially greater yield than the less weathered Lahaina and Pearl Harbor soils.

The relative insensitivity of sugarcane to levels of Ca in the Kapaa, Lahaina and Pearl Harbor soils and to levels of Ca at the lowest K level of the Akaka soil is surprising at first but is in keeping with the low tenacity with which these soils hold Ca. Rixon and Sherman (1962) reported that pH of unlimed, Hydrol Humic Latosols range from 4.7 to 5.4, but that acidity *per se*, apparently has no influence upon the growth of sugarcane. Mclean (1970) advocated that when all nutrients are supplied in adequate amounts and no elements are of significant

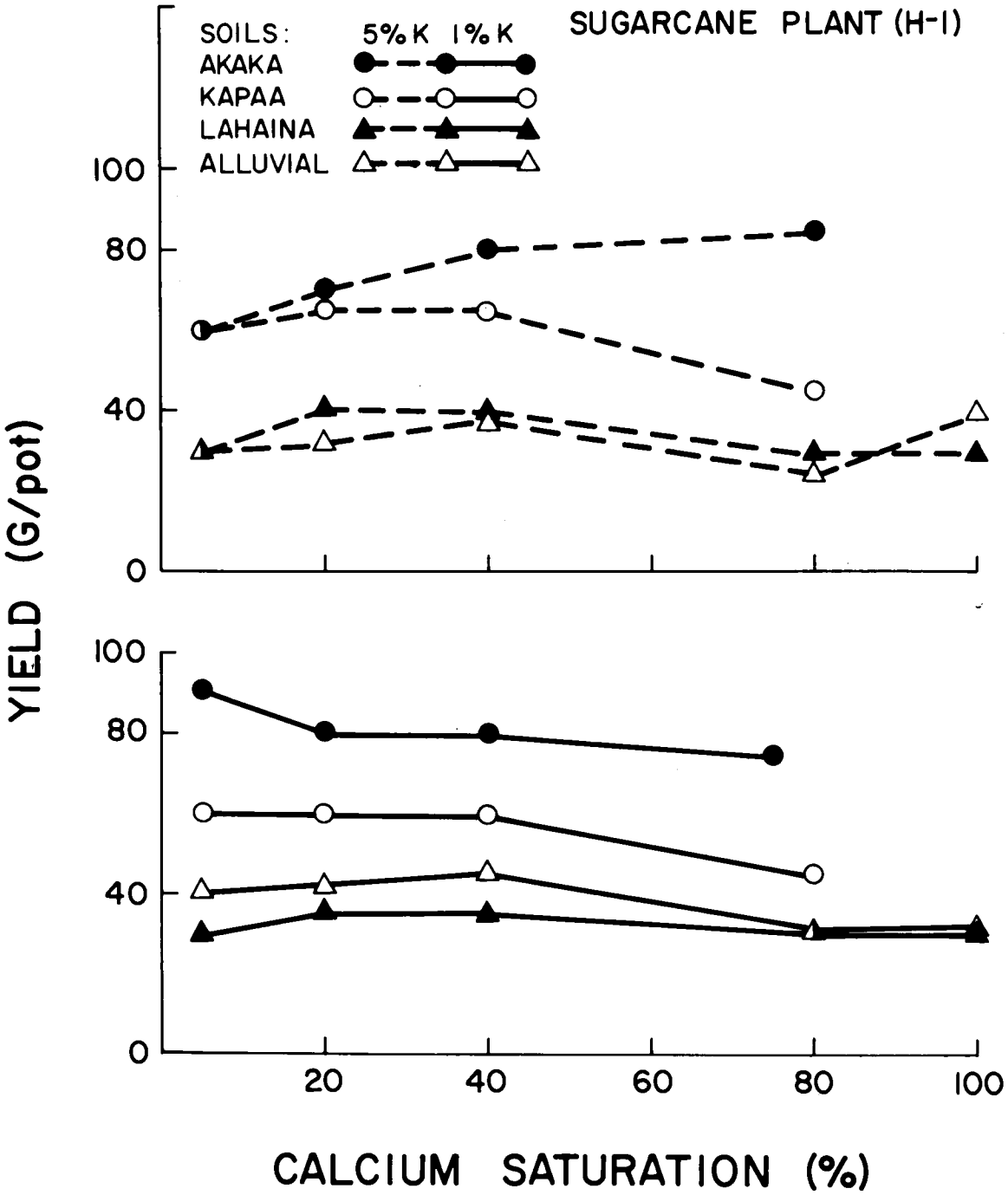

SUGARCANE PLANT (H-1)
SOILS:
5% K
1% K
AKAKA
KAPAA
LAHAINA
ALLUVIAL
YIELD (G/pot)
100
80
40
0
20
40
60
80
100
CALCIUM SATURATION (%)

FIGURE 2. SUGAR CANE YIELD IN RELATION TO PERCENTAGE CA AND K SATURATION OF FOUR SOILS (HARVEST NO. 1)

TABLE III. INFLUENCE OF CA AND K SATURATION OF FOUR SOILS ON THE MEAN YIELD OF THE FIRST AND THE SECOND SUGARCANE HARVEST

Cation Saturation (%)		First Harvest				Second Harvest			
Ca	K	Akaka	Kapaa	Lahaina	Pearl Harbor	Akaka	Kapaa	Lahaina	Pearl Harbor
		← gms/pot →							
5	1	90	60	30	40	60	95	25	15
20	1	80	60	35	40	80	85	20	60
40	1	80	60	35	45	70	85	30	60
80	1	75	45	30	30	85	80	60	50
100	1	-	-	30	30	-	-	50	50
5	5	60	60	30	30	55	120	40	40
20	5	70	65	40	30	85	85	30	70
40	5	80	65	40	35	105	85	15	70
80	5	85	50	30	25	140	95	75	35
100	5	-	-	30	40	-	-	60	70

concentration to be toxic, maximum yields can be obtained at pH values considerably lower than neutral. In the present experiment, plant growth in Akaka and Kapaa soils indicate adequate Ca and K nutrition even at low pH and low Ca saturations. No deficiency or toxicity symptoms were observed in sugarcane plants grown on these soils.

In general, liming at the highest K level was effective but the effect was more in the case of the Akaka soil compared to other soils. This suggests the need for additional Ca when soil K is very high. Carolus (1949) found that when lime and K were added together, highly significant increase in tomato yield was obtained.

These data indicate that cane yields were independent of pH adjustments resulting from liming. The only exception was the Akaka soil which gave increasing yield with increasing Ca saturation at the highest K level. Since increasing pH should depress the solubility of toxic elements such as Al, Fe and Mn it is probably unwise to attempt an explanation on these grounds. The lack of good explanation for these data emphasize how much there is to learn about the main effects and side effects of liming tropical soils.

Ca composition of plants

The Ca composition of sugarcane increased with increasing Ca saturation of the soils. Plant composition varied considerably from soil to soil (Figs. 3 to 6 and Table IV). These data are in general agreement with the body of literature accumulated on this subject for other plants and soils which have been reviewed in the literature section. Several features of the data are of special interest. First, plant Ca was in the normal range at very low levels of Ca in the soil.

FIGURE 3. CA CONTENT OF CANE LEAVES IN RELATION TO PERCENTAGE CA AND K SATURATION OF FOUR SOILS (HARVEST NO. 1)

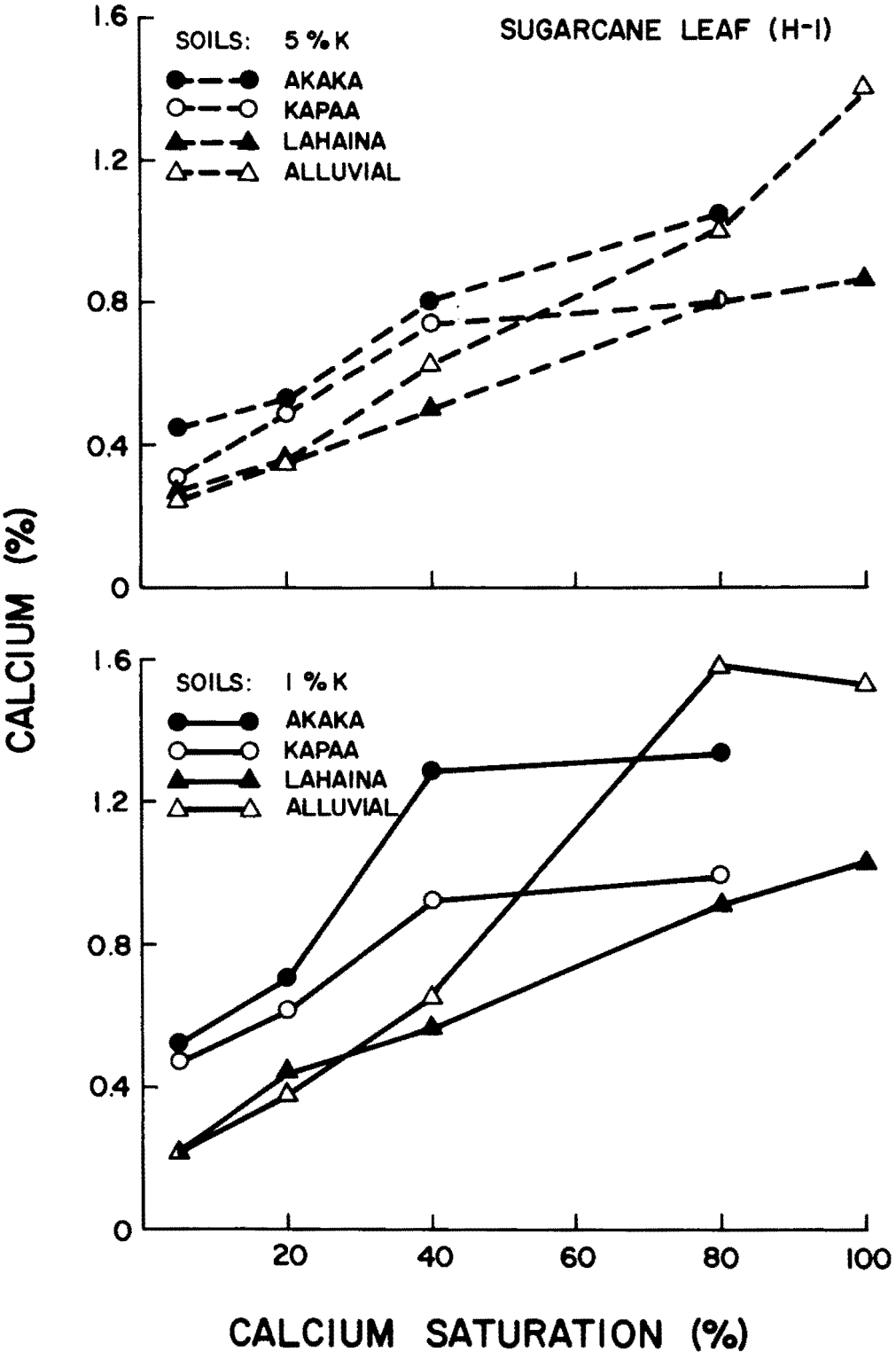

SUGARCANE LEAF (H-1)
SOILS: 5 % K
AKAKA
KAPAA
LAHAINA
ALLUVIAL
SOILS: 1 % K
AKAKA
KAPAA
LAHAINA
ALLUVIAL
CALCIUM (%)
CALCIUM SATURATION (%)
0
0.4
0.8
1.2
1.6
20
40
60
80
100

FIGURE 4. CA CONTENT OF CANE LEAVES IN RELATION TO PERCENTAGE CA AND K SATURATION OF FOUR SOILS (HARVEST NO. 2)

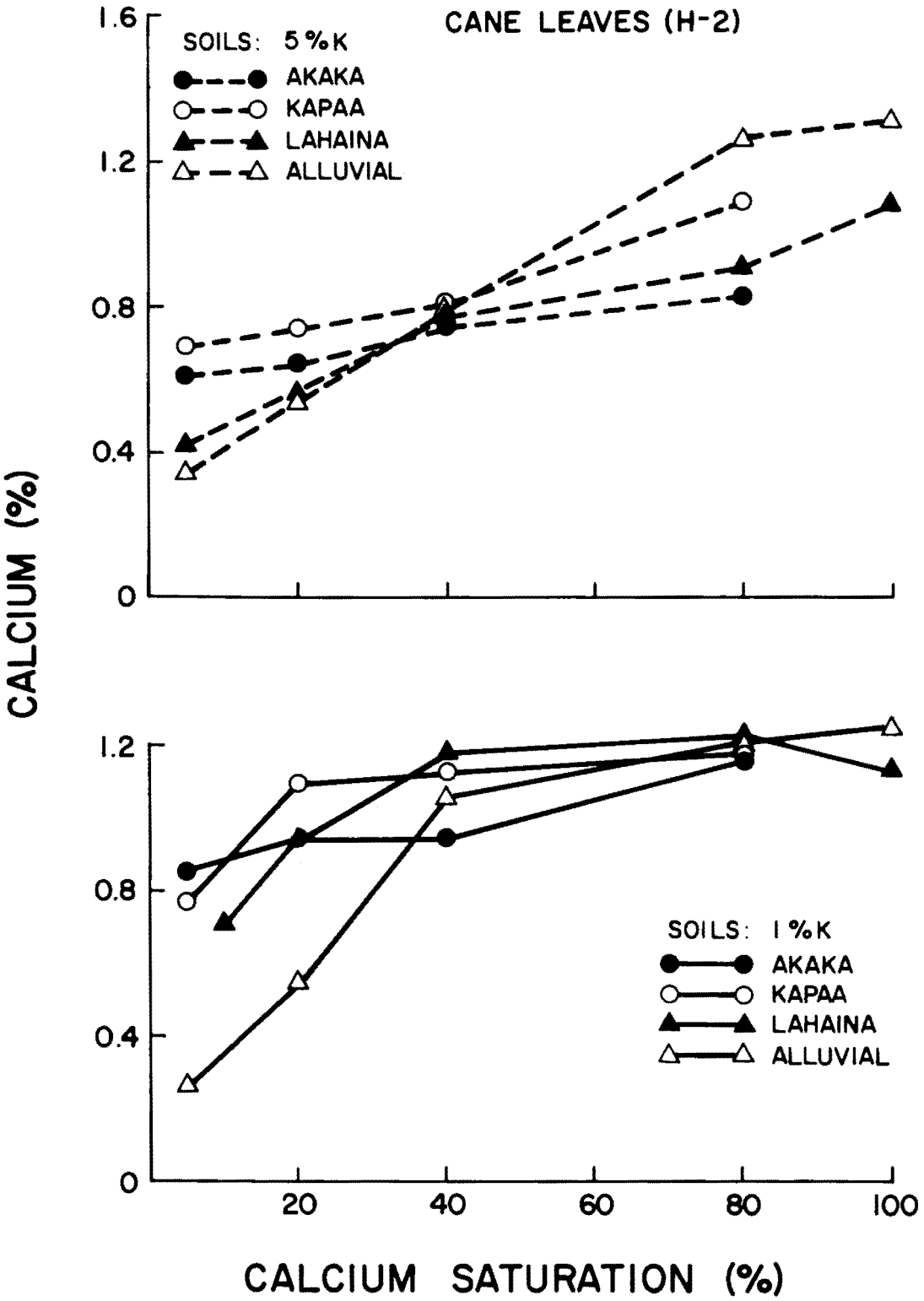

CANE LEAVES (H-2)
SOILS: 5 %K
AKAKA
KAPAA
LAHAINA
ALLUVIAL
SOILS: 1 %K
AKAKA
KAPAA
LAHAINA
ALLUVIAL
CALCIUM (%)
CALCIUM SATURATION (%)
0
0.4
0.8
1.2
1.6
20
40
60
80
100

FIGURE 5. CA CONTENT OF CANE SHEATHS IN RELATION TO PERCENTAGE CA AND K SATURATION OF FOUR SOILS (HARVEST NO. 1)

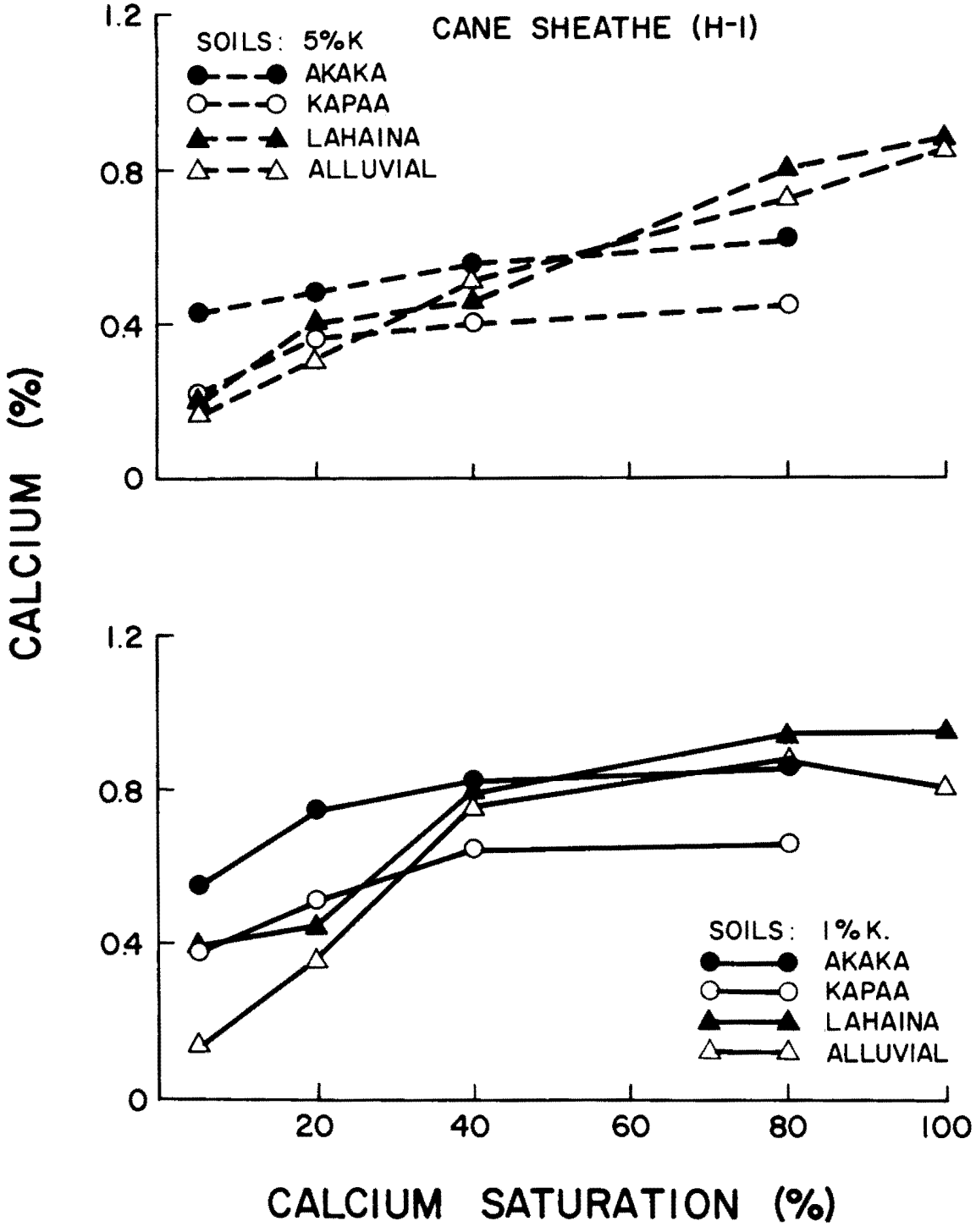

CANE SHEATHE (H-I)
SOILS: 5%K
AKAKA
KAPAA
LAHAINA
ALLUVIAL
1.2
0.8
0.4
0
SOILS: 1%K.
AKAKA
KAPAA
LAHAINA
ALLUVIAL
20
40
60
80
100
CALCIUM (%)
CALCIUM SATURATION (%)

FIGURE 6. CA CONTENT OF CANE SHEATHS IN RELATION TO PERCENTAGE CA AND K SATURATION OF FOUR SOILS (HARVEST NO. 2)

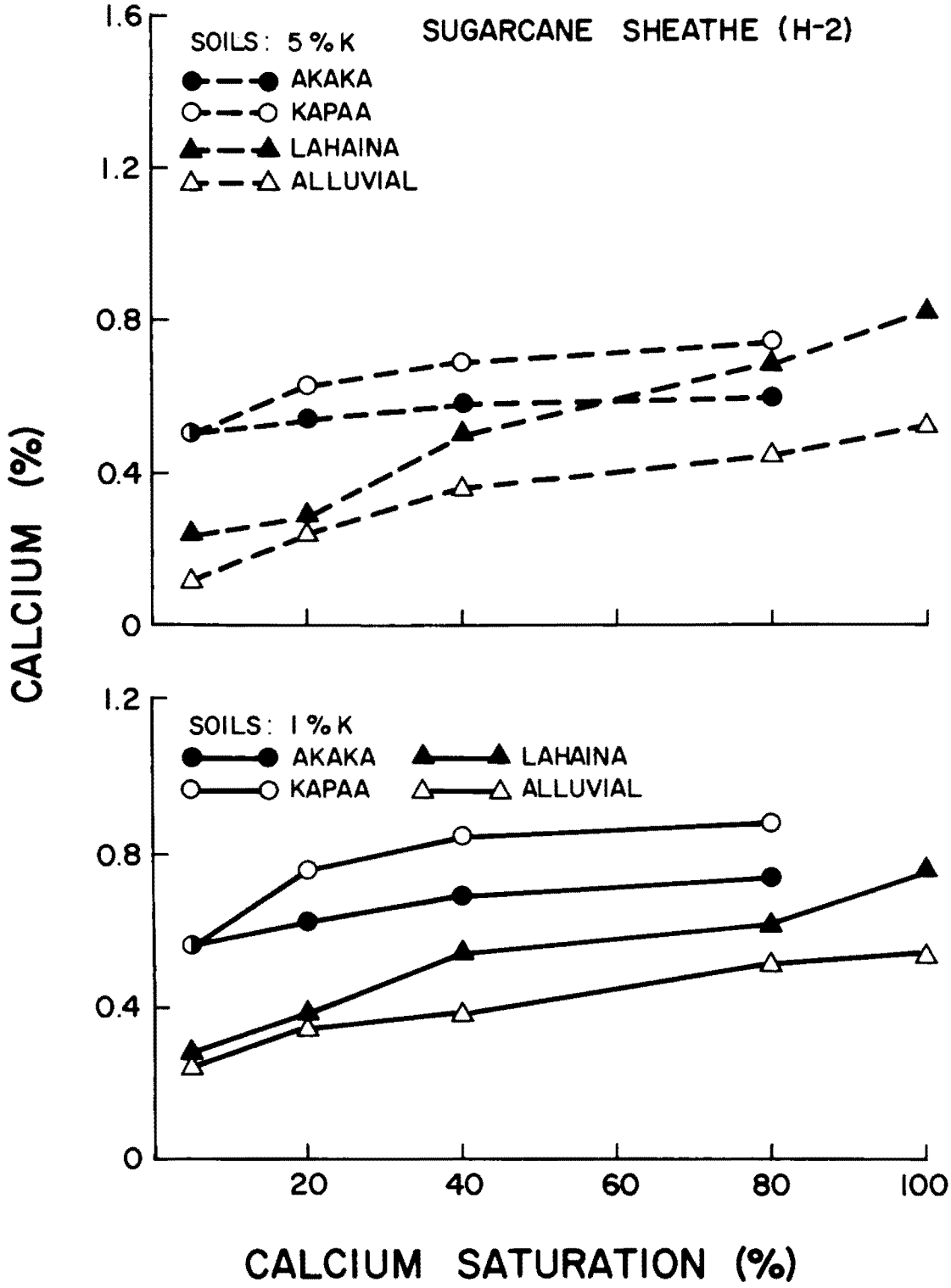

SUGARCANE SHEATHE (H-2)
SOILS: 5 % K
AKAKA
KAPAA
LAHAINA
ALLUVIAL
SOILS: 1 % K
AKAKA
KAPAA
LAHAINA
ALLUVIAL
CALCIUM (%)
CALCIUM SATURATION (%)
0
0.4
0.8
1.2
1.6
20
40
60
80
100

TABLE IV. INFLUENCE OF CA AND K SATURATION OF FOUR SOILS ON THE MEAN CA CONTENT OF CANE LEAVES AND SHEATHS FROM TWO CANE HARVESTS

Cation Saturation (%)		First Harvest				Second Harvest			
Ca	K	Akaka	Kapaa	Lahaina	Pearl Harbor	Akaka	Kapaa	Lahaina	Pearl Harbor
		← Ca in leaves (%) →							
5	1	0.50	0.45	0.20	0.20	0.85	0.80	0.70	0.30
20	1	0.70	0.60	0.45	0.40	0.95	1.10	0.95	0.55
40	1	1.30	0.90	0.60	0.60	0.95	1.15	1.20	1.05
80	1	1.35	1.00	0.90	0.90	1.15	1.20	1.25	1.20
100	1	-	-	1.00	1.00	-	-	1.15	1.25
5	5	0.45	0.30	0.30	0.30	0.60	0.70	0.40	0.35
20	5	0.50	0.45	0.40	0.35	0.65	0.75	0.60	0.55
40	5	0.80	0.75	0.50	0.60	0.75	0.80	0.80	0.80
80	5	1.05	0.80	0.80	1.00	0.80	1.05	0.90	1.25
100	5	-	-	0.90	1.40	-	-	1.20	1.30
		← Ca in sheaths (%) →							
5	1	0.55	0.40	0.40	0.15	0.55	0.55	0.30	0.25
20	1	0.75	0.50	0.45	0.40	0.60	0.80	0.40	0.35
40	1	0.80	0.65	0.80	0.80	0.70	0.85	0.55	0.40
80	1	0.90	0.70	0.95	0.90	0.75	0.90	0.60	0.50
100	1	-	-	0.95	0.80	-	-	0.80	0.55
5	5	0.40	0.20	0.20	0.20	0.50	0.50	0.25	0.12
20	5	0.50	0.35	0.40	0.30	0.55	0.60	0.30	0.25
40	5	0.60	0.40	0.45	0.50	0.60	0.70	0.50	0.40
80	5	0.65	0.45	0.80	0.75	0.60	0.75	0.70	0.45
100	5	-	-	0.90	0.90	-	-	0.80	0.50

Clements (1962) suggested that for full growth of sugarcane, Ca in sheaths should be 0.15 to 0.17 percent. In general, sheath Ca exceeded suggested critical levels at all levels of Ca saturation. The only exception was the Pearl Harbor soil which was below the critical level at 5% Ca saturation. Secondly, differences among soils were evident in the concentration of Ca in plant tissues. However, at high levels of Ca saturation sheath Ca of the first harvest tended to be greatest for sugarcane growing on the Lahaina and Pearl Harbor soils. A third interesting feature of the data is the influence of soil K on Ca in leaf and sheath tissues. In general, plant Ca was greater at the 1% K saturation than at the 5% K saturation.

It is obvious from these data that Ca nutrition of sugarcane can be adequate at low soil pH and at low Ca saturation. Therefore, liming recommendation for sugarcane soils might well be based on criteria other than pH. The HSPA Experiment Station bases their liming recommendation on the amount of Ca in the soil without regard to soil pH or exchange capacity. This practice seems justified on the basis of data presented here. The work of Mahilum, Fox and Silva (1970) on the Akaka soil has demonstrated that exchange capacity, as determined in the traditional manner, has little meaning as a basis for understanding Ca movement in the soil or Ca nutrition of the sugarcane plant. They suggest that the percentage saturation of permanent charges would be more meaningful. Permanent charge as estimated by the sum of exchangeable cations including Al + H was very much lower than CEC determined at pH 7. Even so, Ca nutrition of sugarcane was apparently adequate when Ca made up about 12% of the adsorbed cations. Therefore,

one can conclude that Ca is much more available when it is adsorbed on colloids in highly weathered soils than when adsorbed by crystalline clay minerals, especially those of the 2:1 type.

Total Ca content of plants

The absolute amount of Ca in plant tops was smallest in plants grown on the Lahaina soil and greatest in plants grown on the Akaka soil. The Kapaa soil tended to be similar to the Akaka soil whereas the Pearl Harbor soil more closely resembled the Lahaina soil (Appendix Table II).

The calculated values for percent Ca saturation in soils after the first harvest are presented in Appendix Table III. These values were greater for the Lahaina and Pearl Harbor soils than for the Akaka and Kapaa soils because the first crop grew less vigorously on these soils. Despite greater exchangeable Ca in Lahaina and Pearl Harbor soils after the first harvest, the % Ca and total Ca content of plants of the second harvest were greater in the Akaka soil than other soils, especially at low levels of Ca saturation. The Kapaa soil closely resembled the Akaka soil in this respect. The data show that plants growing on the Akaka soil extracted Ca much more readily than plants growing on the Lahaina and Pearl Harbor soils, showing that the Akaka soil which has a considerable component of positive charge may supply adequate Ca even if this element occurs in small quantities.

These considerations lead one to conclude that under the conditions of this experiment Ca availability is greater from the highly weathered soils than the less weathered soils, especially at low pH and at low Ca saturation.

K Composition of plants

The percentage K composition of sugarcane was influenced by the nature of the soil and degree of K saturation (Figures 7 to 10 and Table V). In general, the concentrations of K in plants grown on the Lahaina and Pearl Harbor soils were greater than in plants grown on the Akaka and Kapaa soils. Clements (1964) considered K supply inadequate when K content of young sheaths dropped below 2.25 percent. This was expressed as percent of sugar free dry matter. In the case of the first harvest, at the lowest K level, sheath K was below the critical level at all Ca saturations. The percent K in sheaths was above minimum at 40 and 80% Ca saturation of the Kapaa soil only. On the other hand, sheath K was above the critical level in the Lahaina and Pearl Harbor soils. When the K level was raised to 5%, all the four soils were in excess of the minimum requirement.

In the second harvest, the K composition of sheaths was far below the required level in the Akaka, Kapaa and Pearl Harbor soils at the 1% K level. The K concentration of sheath in the Kapaa, Lahaina and Pearl Harbor soils was in excess of the critical level at the 5% K level. The only exception was the Akaka soil which was below the minimum K level at 20, 40 and 80% Ca saturation.

Differences among soils were evident in the concentration of K in plant tissues. The mean values for percent K composition of plant tops (leaves + sheaths) for each soil from two cane harvests was as follows:

FIGURE 7. K CONTENT OF CANE LEAVES IN RELATION TO PERCENTAGE CA AND K SATURATION OF FOUR SOILS (HARVEST NO. 1)

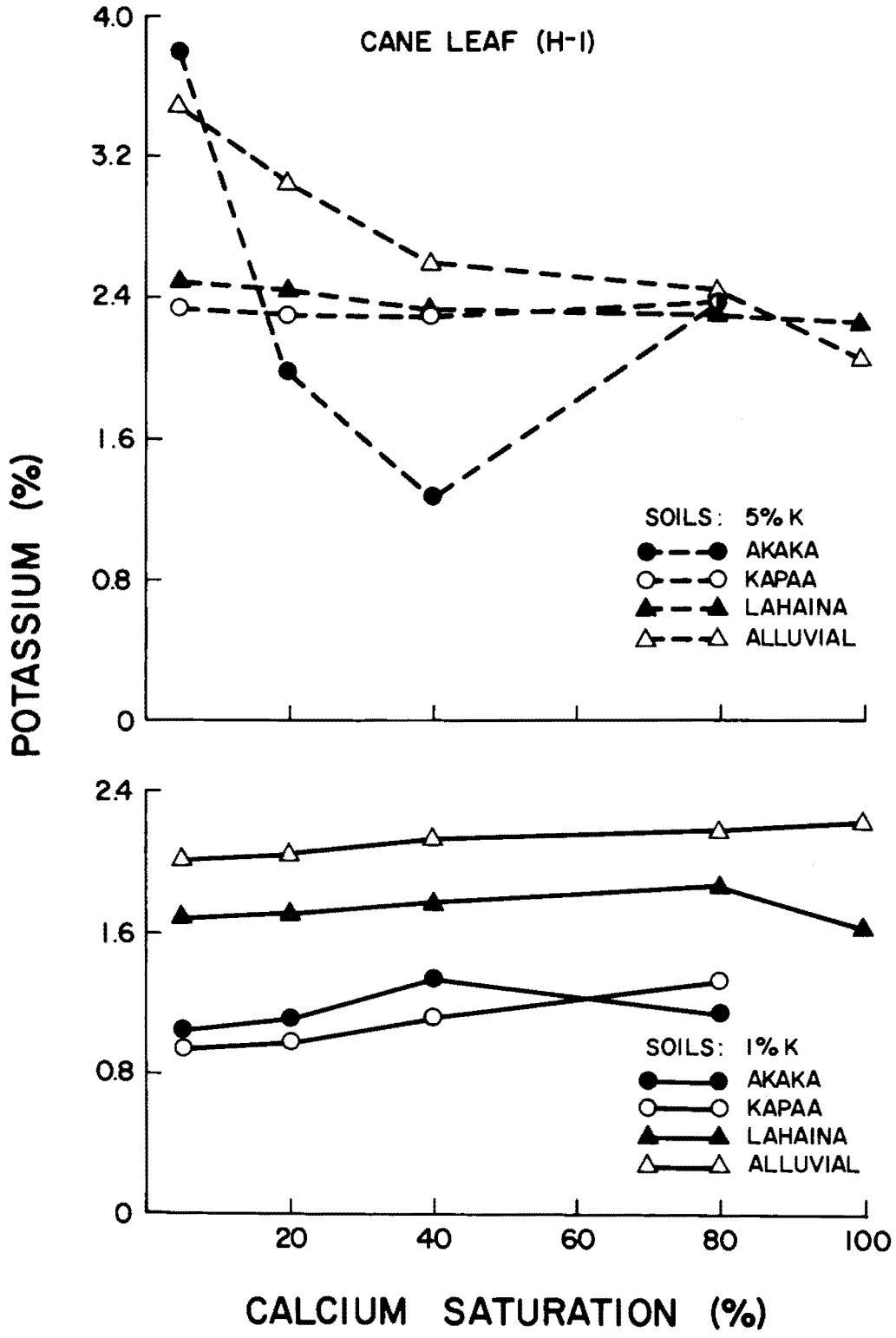

CANE LEAF (H-1)
POTASSIUM (%)
4.0
3.2
2.4
1.6
0.8
0
SOILS: 5% K
AKAKA
KAPAA
LAHAINA
ALLUVIAL
2.4
1.6
0.8
0
SOILS: 1% K
AKAKA
KAPAA
LAHAINA
ALLUVIAL
20
40
60
80
100
CALCIUM SATURATION (%)

FIGURE 8. K CONTENT OF CANE LEAVES IN RELATION TO PERCENTAGE CA AND K SATURATION OF FOUR SOILS (HARVEST NO. 2)

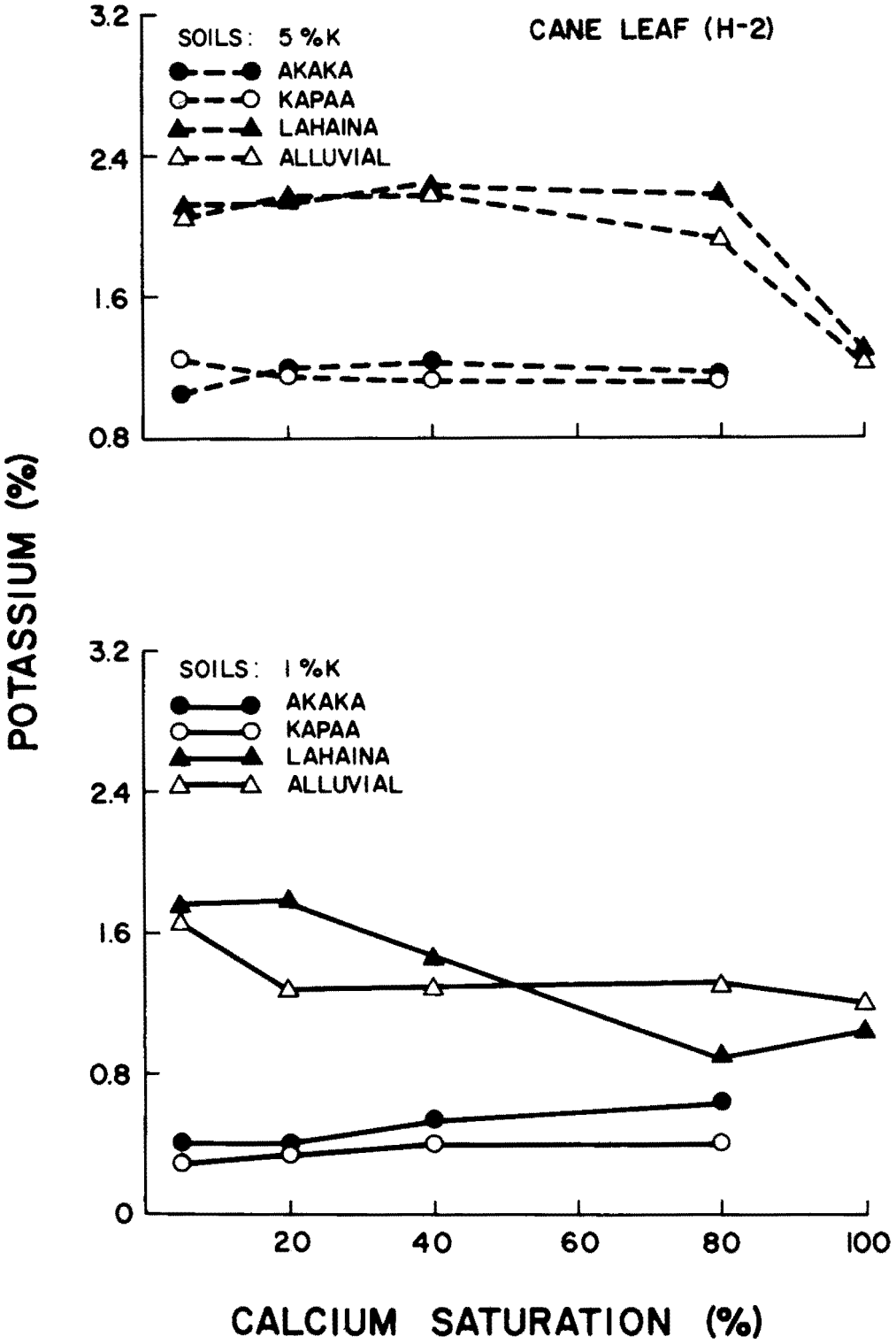

CANE LEAF (H-2)
SOILS: 5 %K
AKAKA
KAPAA
LAHAINA
ALLUVIAL
SOILS: 1 %K
AKAKA
KAPAA
LAHAINA
ALLUVIAL
3.2
2.4
1.6
0.8
0
20
40
60
80
100
POTASSIUM (%)
CALCIUM SATURATION (%)

FIGURE 9. K CONTENT OF CANE SHEATHS IN RELATION TO PERCENTAGE CA AND K SATURATION OF FOUR SOILS (HARVEST NO. 1)

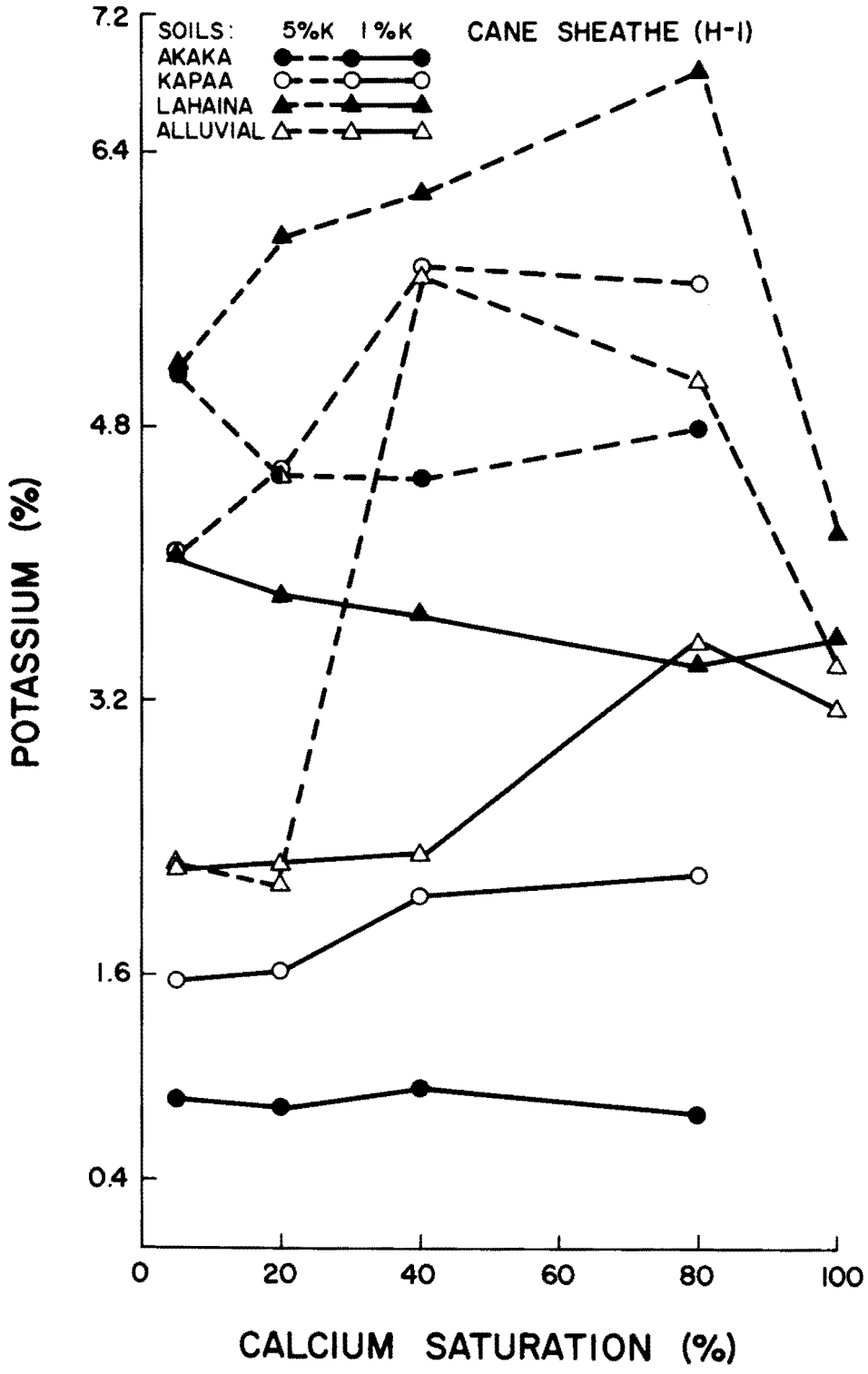
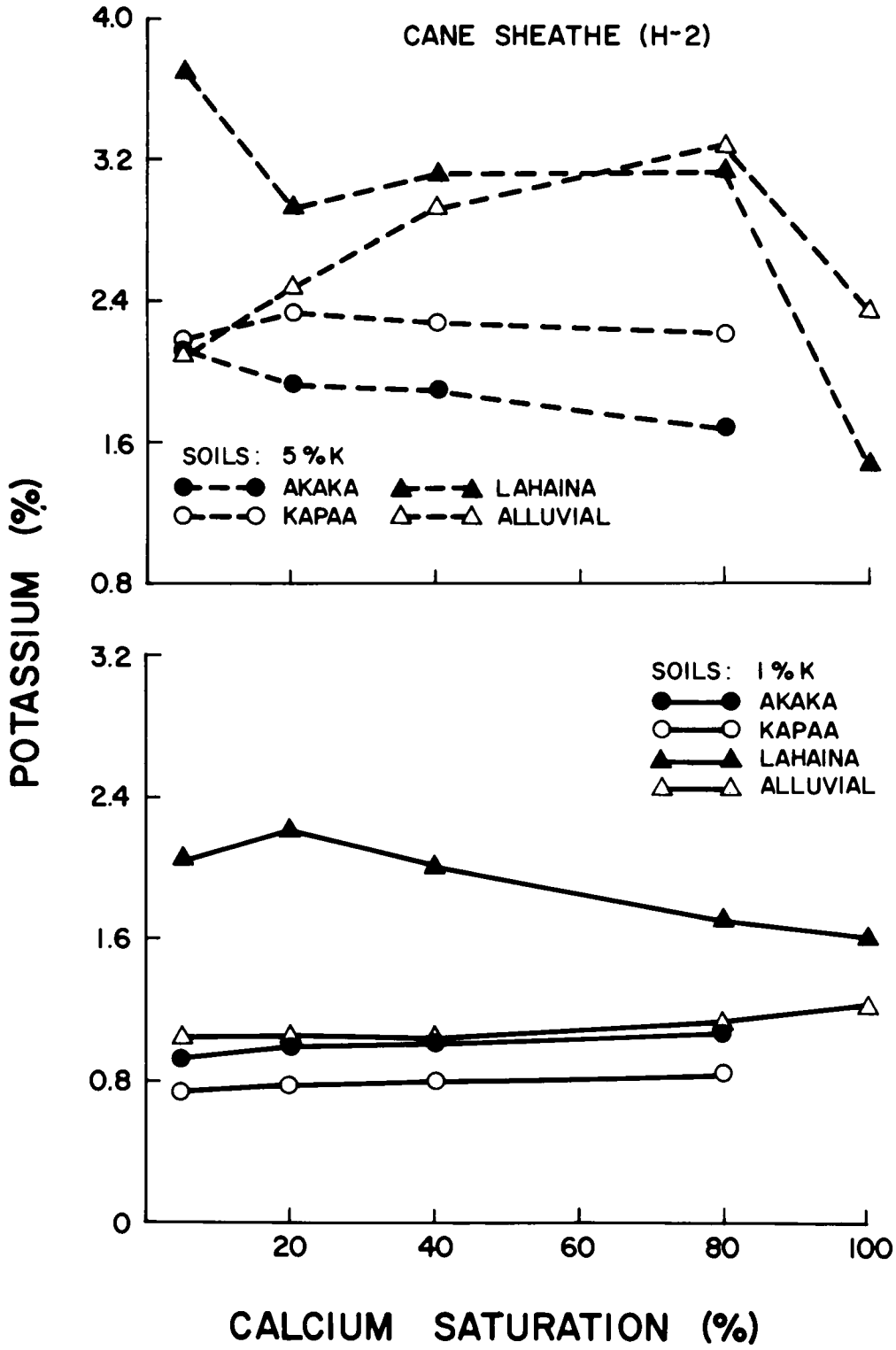

SOILS: 5%K 1%K
AKAKA
KAPAA
LAHAINA
ALLUVIAL
CANE SHEATHE (H-1)
7.2
6.4
4.8
3.2
1.6
0.4
POTASSIUM (%)
0
20
40
60
80
100
CALCIUM SATURATION (%)

FIGURE 10. K CONTENT OF CANE SHEATH IN RELATION TO PERCENTAGE CA AND K SATURATION OF FOUR SOILS (HARVEST NO. 2)


CANE SHEATHE (H-2)
4.0
3.2
2.4
1.6
0.8
SOILS: 5 % K
AKAKA
LAHAINA
KAPAA
ALLUVIAL
SOILS: 1 % K
AKAKA
KAPAA
LAHAINA
ALLUVIAL
3.2
2.4
1.6
0.8
0
20
40
60
80
100
POTASSIUM (%)
CALCIUM SATURATION (%)